

5G Converged Cell-less Communications in Smart Cities

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Abstract

Ubiquitous information service converged by different types of heterogeneous networks is one of fundamental functions for smart cities. Considering the deployment of 5G ultra-dense wireless networks, the 5G converged cell-less communication networks are proposed to support mobile terminals in smart cities. To break obstacles of heterogeneous wireless networks, the 5G converged cell-less communication network is vertically converged in different tiers of heterogeneous wireless networks and horizontally converged in celled architectures of base stations/access points. Moreover, the software defined network controllers are configured to manage the traffic scheduling and resource allocation in 5G converged cell-less communication networks. Simulation results indicate the coverage probability and the energy saving at both base stations and mobile terminals are improved by the cooperative grouping scheme in 5G converged cell-less communication networks.

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I. INTRODUCTION

Smart cities are the evolution trends of future cities, which involve in many aspects of the daily life in cities, such as e-businesses, intelligent transportation systems, telemedicine, metropolis managements, security surveillances, logistical managements, social networks, community services and so on. To brace above services, smart cities have been employing various wireless communication technologies and networks, including the bluetooth, ZigBee, radio frequency identification (RFID) wireless technologies, wireless cellular networks, wireless local area networks (WLANs), radio broadcasting networks, wireless sensor networks, body area networks and many others [1]. These wireless communication technologies along with fiber communication networks and cable networks form the ubiquitous networks for smart cities. Furthermore, these different types of heterogeneous wireless networks are expected to support the mobile Internet, internet of things (IoT), cloud computing [2] and big data in smart cities.

In future smart cities, the different types of information need to be smoothly transmitted by different types of heterogeneous wireless networks with the high data rate and the low energy consumption. In this case, the simple inter-connection with different types of heterogeneous wireless networks can not support the ubiquitous information services of future smart cities. Furthermore, the mobile converged network has been proposed to satisfy the high data rate and the low energy consumption [3]. Compared to the simple inter-connection scheme, a new network architecture needs to be proposed for the convergence of heterogeneous networks based on different transmission technologies in smart cities. In general, there are two levels of heterogeneity of communication networks in smart cities. One of the levels refers to the different transmission technologies among bluetooth, ZigBee, WLAN, millimeter wave, and even visible light communication (VLC) [4], while another level of heterogeneity is related to different configurations and parameters of the same transmission technology, e.g., a heterogeneous cellular network is consisted of a macro cell tier, a few micro-cell tiers and femto-cell tiers [5]. Conventional communication networks including cellular networks and WLANs have a distinct characteristic, i.e., there are regional areas around the base stations (BSs) or the access points (APs), in which mobile terminals have to access the network via its associated BS or AP. Such an area can be defined as a “cell” associated to a BS in cellular networks, or just a “covered area” associated to an AP in WLANs. In this article, both of them are named as “cells” for the

sake of convenience. In conventional heterogeneous cellular scenarios, a mobile terminal has to handover vertically among heterogeneous network tiers, or handover horizontally among adjacent cells in the same tier. As a consequence, it is required to perform complicated switching and routing algorithms across various types of heterogeneous networks. By some recent research, Software Defined Network (SDN), which had been introduced to wired networks many years ago, has been using in managing complicated mobile networks and performing the traffic routing in new generation networks [6], and SDN is also suitable to manage complicated heterogeneous networks [7] such as 5G networks in smart cities. Some researches show that SDN can be improved to manage dynamic links such as access network links or 5G backhaul links, which are widely required in coordinated multipoint transmission networks [8]. To realize ubiquitous and universal network services in smart cities, we try to use SDN technology to break the technology gaps and regional strict in both vertically tier-ed and horizontally celled heterogeneous networks for support the ubiquitous information services in smart cities.

The most important contribution of this article is to show that a 5G converged cell-less communication scheme is proposed to meet rising challenges in smart cities, such as heterogeneous wireless transmission technologies and interference. Numerical results indicate that the proposed 5G converged cell-less communication network has a better coverage performance and higher energy efficiency compared with conventional cellular networks. In Section II the architecture and model of cell-less communication networks is introduced for smart cities. The performance of the 5G converged cell-less communications is investigated by evaluating the performance of coverage and energy efficiency in Section III. The future challenges of the 5G converged cell-less communications in smart cities are discussed in Section IV. The conclusion is drawn in Section V.

II. ARCHITECTURE AND MODEL OF CELL-LESS COMMUNICATIONS IN SMART CITIES

A. *From Celled Networks to Cell-less Networks*

There are many challenges for the mobile and wireless communications in smart cities. Based on the development of 5G communication systems, some of issues involving with the urban scenarios are list as follows.

- 1) The huge demand of data rate causes ultra-densified BSs/APs deployment. There are three main approaches for 5G communication systems to increase data rate significantly, i.e.,

the wider spectrum of millimeter wave transmission, the more spatial diversity of massive MIMO and the more spatial density of BSs/APs. Deploying more BSs/APs can serve more high-data-rate-demanding users and thereby provide a higher achievable data rate in terms of per unit area in smart cities. The higher density of BSs/APs makes the smaller cell coverage as the distance between BSs/APs is reduced to tens meters for satisfying the high-data-rate-demanding in smart cities [9].

- 2) The movement of mobile terminals in modern metropolitan scenarios becomes more complex and volatile. In a prosperous city, the movement of mobile nodes is varied and complicated [10]. In smart cities, a mobile terminal with data transmission can be a mobile phone carried by a pedestrian, a navigation device installed on a moving car or a PDA used in a high speed train. And what is more, various types of mobile nodes make the mobility situation even harder to handle. For example, there are completely different communication requirements between the scenarios of densified RFID labels going through a gate and a mobile high definition surveillance camera moving around in a disaster scene.
- 3) In urban areas, buildings and trees become obstacles to wireless communications. The wireless communication channels are very different between indoor and outdoor environments. The designers of mobile communication systems have to consider the obvious impact of obstacles, especially for the millimeter wave wireless transmission in the emerging 5G communication networks, which is of very short wave length and hard to diffract in smart cities.

With regard to above demands to the mobile communications in smart cities, current heterogeneous networks based on different types of communication technologies meet many issues for the ubiquitous information services in smart cities and some of them are listed as below.

- 1) Issue of network convergence. To overcome problems of the vertical and horizontal handover and routing across tiers, how to converge the heterogeneous networks becomes a critical issue. For the prevailing wireless transmission technologies and communication networks, it is hard to converge them with each other seamlessly. Instead, they interconnect with each other, in this way, many issues regarding routing and protocols remain in heterogeneous wireless networks.
- 2) Issue of load balancing in celled networks. Along with the decreasing of the cell size,

the traffic loads of cells get more and more unbalanced. Moreover, the traffic load of smart cities is obviously fluctuated over space and time domains. The fluctuation of traffic load in space domain is caused by the stochastic spatial distribution of communication nodes in smart cities, e.g., the data centers of smart cities are stochastic distributed in different places. The fluctuation of traffic load in time domain is created by the mobility of terminals scheduled by the work and life in smart cities [11]. For the improving of signal-to-interference-plus-noise ratio (SINR) in wireless communications, the sizes of cells in mobile networks get smaller to gain higher data rate matching the terminal's higher data rate demand. As we know, the bigger size of a cell can smooth the random fluctuation in space domain. When the size of a cell is getting small in 5G networks, the traffic load balance issue emerges for smart cities.

- 3) Issue of handover. When the cell size is reduced to tens meters in 5G cellular networks, the quickly moving terminals lead to frequent handovers in 5G cellular networks and additional latency is inevitable for wireless communications. When the handover occurs between different types of heterogeneous wireless networks, a large amount of overhead in wireless network will decrease the data exchanging efficiency.
- 4) Issue of interference. In an interference-limited conventional cellular network, the increase of BS/AP density doesn't lead to the increase of the average interference indicator [12]. However, the densified BSs/APs under complicated electromagnetic environments in smart cities may face the highly correlative interference or noise and hence the performance of some adjacent BSs/APs drops significantly [13]. It is an important concern to eliminate spatially correlative interference in the dense wireless networks of smart cities.

From what we discuss above, deploying conventional cellular network can not solve above issues and satisfy the ubiquitous information services in smart cities. To solve these problems caused by heterogeneity of networks and ultra-density of BSs/APs, we propose to use converged "cell-less" communication networks in stead of "celled" networks to support the mobile users in smart cities.

Fig. 1 illustrates a conventional cellular network and a cell-less network in urban scenarios. As shown in the figure, a mobile terminal in the conventional cellular network always associates to one and only one BS/AP, while a terminal in a cell-less network doesn't associate any BS/AP. In this case, the terminal in a cell-less network can flexibly communicate with one or more BSs/APs

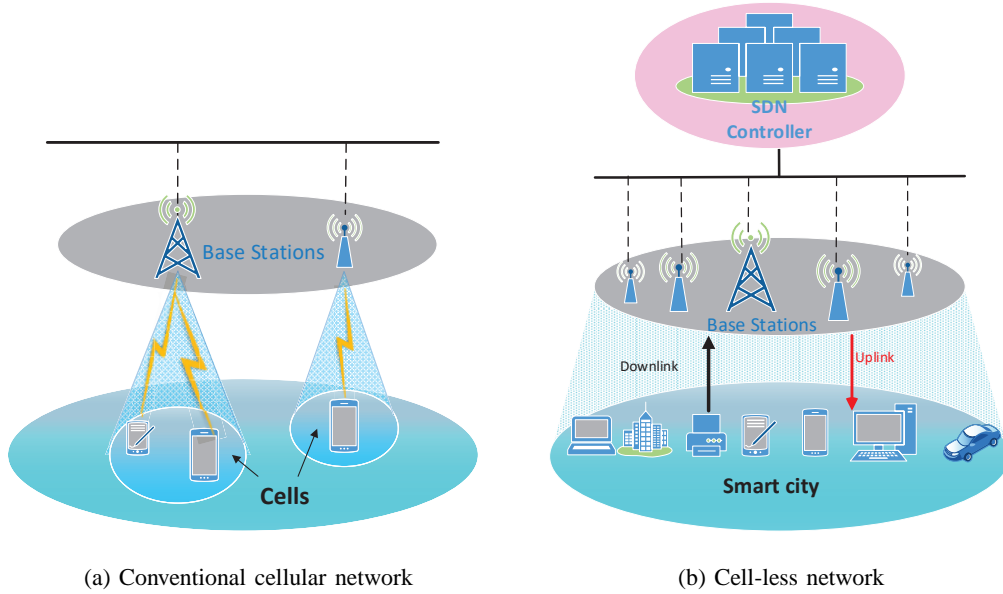


Fig. 1. From a conventional cellular network to a cell-less network

if necessary. In the following parts of the article, we explain the architecture and transmission model of the cell-less communication networks.

B. Architecture of Cell-less Communication Networks in Smart Cities

To match the requirements of huge data rate, ultra-density, high mobility and low energy consumption of wireless networks in smart cities, the 5G converged cell-less communication network is proposed in this paper. In the novel cell-less scheme shown in Fig. 2, a mobile terminal can choose to access one or more BSs/APs by different uplinks and downlinks considering wireless channel status and its demands, or choose not to access any BS/AP when the mobile terminal is idle. That is, a mobile terminal doesn't associate with any BSs/APs before it start to transmit data. In such case, BSs/APs need not maintain a list of associated mobile terminals and instead the SDN controller decides which one or more BSs/APs perform the data transmission for the mobile terminal by the control link shown in Fig. 2. Moreover, the software defined network (SDN) controller creates dynamic backhaul links and downlinks/uplinks as well for the joint transmission or reception group of BSs/APs such that they can cooperate with other members in the same group to support joint transmission and reception for a specified mobile terminal. The cell-less

scheme supports that the number of BSs/APs group is adaptively adjusted by the requirements from the mobile terminal and the wireless channel status in different environments. Therefore, the overhead caused by handover is reduced and the coverage probability is guaranteed for the mobile terminal. Moreover, the traffic load balancing is achieved by resource schedule in a large scale network, which is performed by the SDN controller of converged cell-less communication networks. Furthermore, the traffic load fluctuation in spatial and temporal domains is decreased for smart cities. In this cell-less scheme, the SDN controller and core routers form the SDN cloud, in which the control plane is driven by the cloud computing, while routers and the instantaneous backhaul links form the data plane in the cloud.

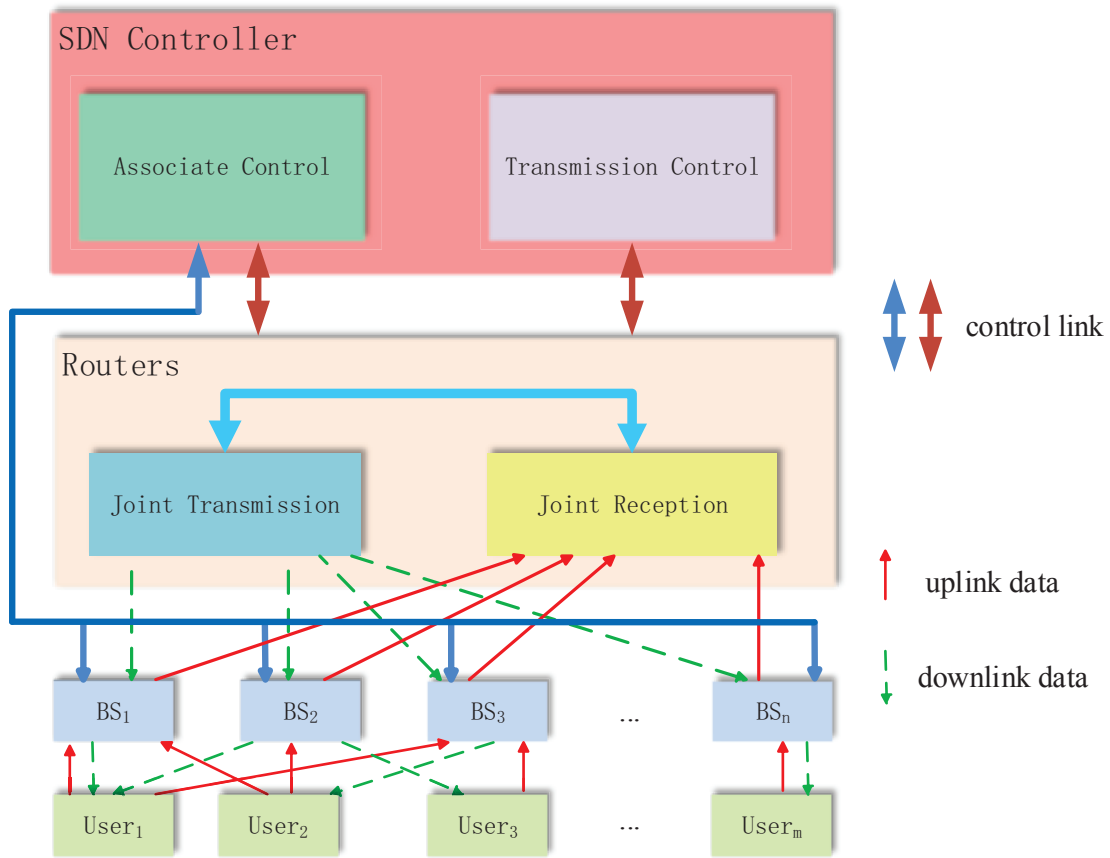


Fig. 2. Cell-less association relations and data transmission are under the control of the SDN controller

C. Transmission Model of Cell-less Wireless Communications

To implement the un-associated transmission between BSs/APs and mobile terminals in cell-less wireless communications, it is necessary to change the access method. Mobile terminals update their locations and channel status around them to the SDN cloud in case the communication to BSs/APs is necessary. As shown in Fig. 3, a mobile terminal transmits the data by broadcasting when it wants to send the uplink data. Nearby BSs/APs receive the data then forward the data to the joint reception controller in the cloud where the data transmitted from the mobile terminal are jointly decoded. When there are data to be sent to a specified mobile terminal, the SDN controller in the cloud decide which one or more of the BSs are chosen to form a cooperative group to perform downlink joint transmission considering the location and channel status around the terminal.

Compared with the conventional celled networks, the 5G converged cell-less communication networks have many advantages listed as below.

- 1) Seamless convergence of heterogeneous networks. Adopting not only inter-connection but also data convergence in terms of transmission environments and user requirements, the cell-less communication networks provide a compelling mechanism to fulfill convergence across tiers and combine their respective advantages as well.
- 2) Superior traffic load management. By cooperation of dynamically grouped BSs/APs in the cell-less scheme, the cell-less communication network can allocate traffic load to BSs/APs under the schedule of the SDN controller.
- 3) Avoiding frequently handovers. In a converged cell-less communication network, a mobile terminal need not associate to any fixed BS. Hence, the frequent handovers between cells are avoided which conduces to the decrease of outage and latency in converged cell-less communication networks.
- 4) Improving of coverage and energy efficiency. When the fixed cell association scheme is given up in heterogeneous wireless networks, the converged cell-less communication networks reorganize the association scheme between the mobile terminals and the BSs/APs in terms of the requirements from users and wireless environments in smart cities. When the flexible grouped cooperative communication is performed, the improved coverage probability is expected for a mobile terminal in converged cell-less communication networks.

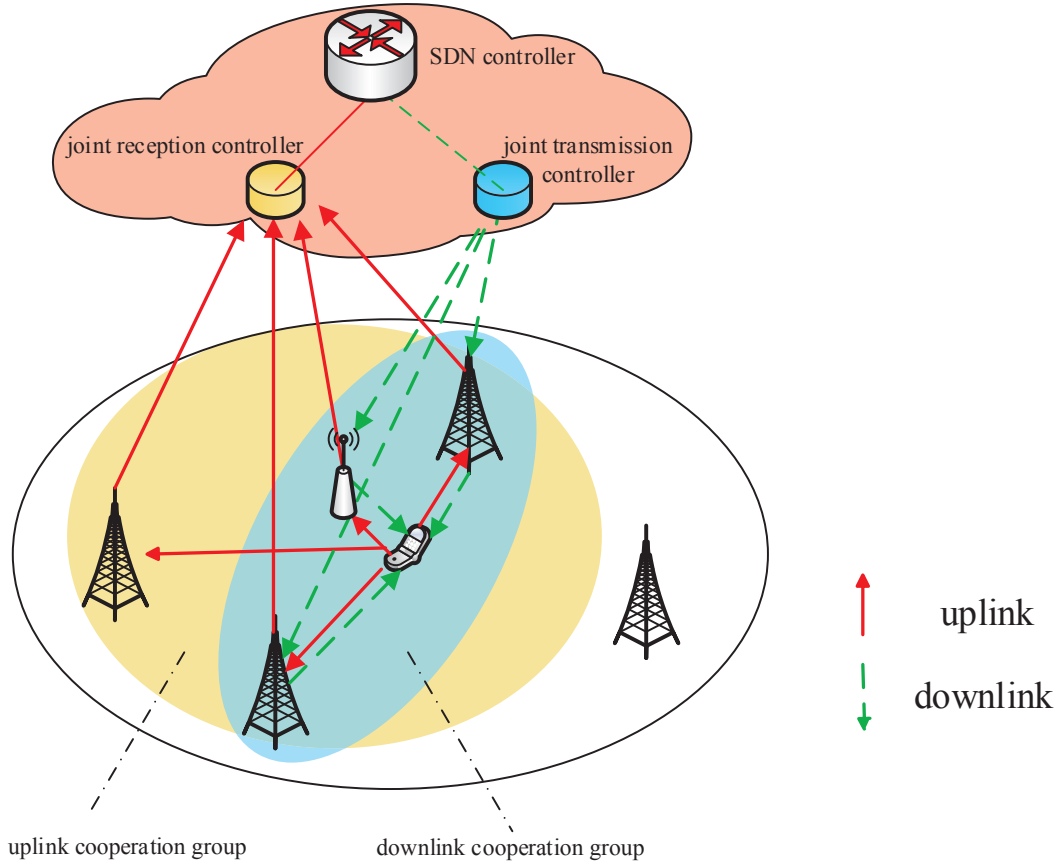


Fig. 3. Transmission model of a cell-less network

Moreover, when the suitable BSs/APs are selected for joint transmission and reception, the energy consumption is also expected to be optimized.

III. COVERAGE AND ENERGY EFFICIENCY OF CONVERGED CELL-LESS COMMUNICATION NETWORKS

A. BS Grouping Scheme for Converged Cell-less Communications Networks

How to form the cooperative group of BSs/APs is a critical issue in converged cell-less communication networks. In generally, the grouping scheme depends on the spatial distribution of BSs/APs and the wireless channel environments in smart cities. The basic criteria of cooperative BSs/APs grouping are suggested as below.

- 1) Criterion of simplicity. Considering the ultra-dense deployment of BSs/APs in smart cities, it is suggested that each station/point serves only one mobile terminal every time if any possible, but one BS/AP is allowed to serve more than one mobile terminal in case there may be congestion in high traffic load scenarios.
- 2) Criterion of economy. As less as possible BSs/APs are selected to form cooperative group, given that the group of BSs/APs meet the user data rate demand.
- 3) Criterion of uniformity between grouping for uplinks and downlinks. The SDN controller will always try to keep the same group for both the uplink and downlink transmission if possible. However, the BSs/APs of the cooperative groups for uplinks and downlinks can be different from each other, especially when the mobile terminal move quickly.
- 4) Employing backhaul multicast capability if any possible. In order to reduce the backhaul overhead, the downlink data is transmitted to the cooperative group by multicast methods if possible.
- 5) Mobility predicting for adjacent mobile terminals. When the BSs/APs are grouped for an active mobile terminals, it is necessary to acquire the distribution of adjacent active and inactive mobile terminals and predict the transmission and reception actions of adjacent active mobile terminals. Furthermore, the size of cooperative group is optimized to avoid the traffic congestion in the hot point.
- 6) Pre-grouping of BSs/APs. Considering that it may be frequently grouped for the cooperative BSs/APs in high traffic load scenarios, a pre-grouping scheme is required to accelerate the grouping speed of cooperative BSs/APs. The pre-grouping scheme is designed by evaluating the recent cooperative grouping result to reduce the computational complexity of cooperative grouping algorithm.

Generally speaking, for indoor scenario where terminals hardly move, the cooperative BS/AP group needn't to be adjusted frequently, while frequent adjusts must be done for quickly moving terminals outdoors. To maintain the quality of communication for fast moving terminals, more BS/AP candidates are beneficial for BS/AP grouping in downlink transmission. Moreover, to maintain a consistent quality of communication, the grouping size should be adjusted when data rate demands of the users vary.

B. Coverage Probabilities in Converged Cell-less Communication Networks

As we know, ultra-dense BSs/APs can be deployed to achieve high data rate in smart cities. Moreover, the coverage of every BS/AP will be reduced by massive MIMO and millimeter wave communication technologies. In this case, the cooperative grouping scheme is a reasonable approach to satisfy the coverage requirement of mobile terminals in smart cities.

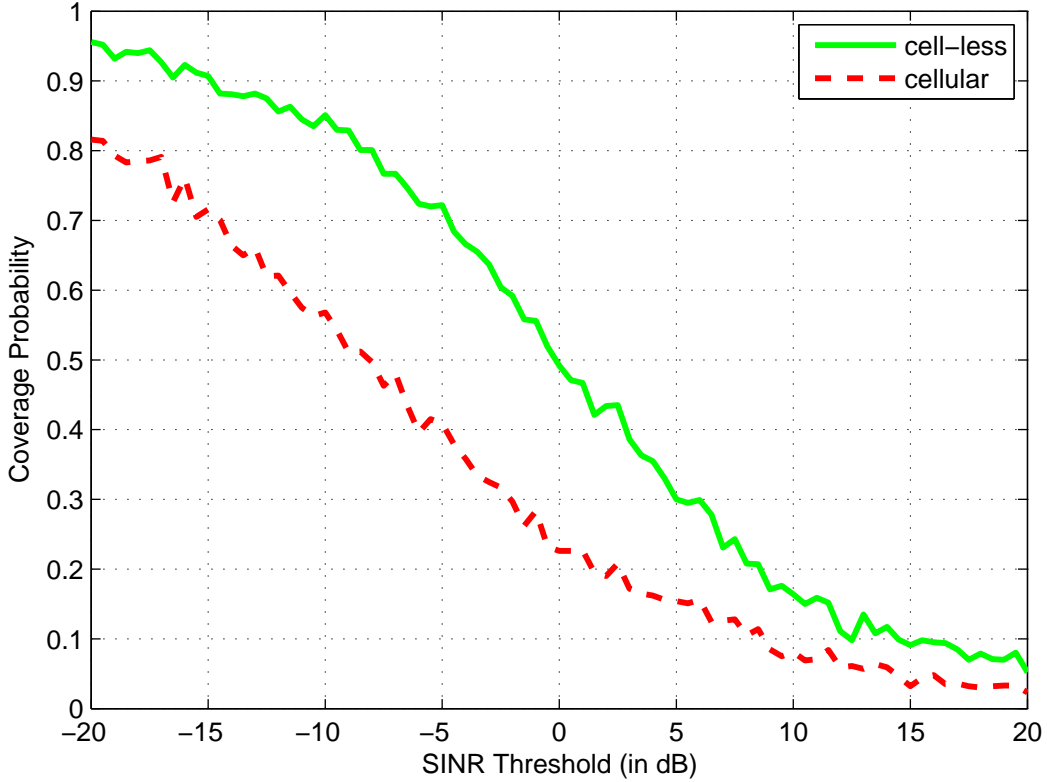


Fig. 4. Coverage probabilities of cellular and cell-less networks

Without loss of generality, in our illustrative example, 50 BSs are deployed into a plane of $50 \text{ m} \times 50 \text{ m}$ randomly. Moreover, 30 BSs are configured as members in active cooperative groups. A typical user is assumed to be located at the central location in the plane. For the sake of simplicity, the nearest 10 BSs around the typical user are configured to be candidates for cooperative grouping in converged cell-less communication networks. The size limit of the cooperative group is no more than 3 BSs in converged cell-less communication networks. If there is no idle BS in candidate BSs, the nearest BS around the typical user is selected to transmit

data even this BS is active in other cooperative group. The coverage probability is analyzed by Monte Carlo simulations in Fig. 4. The results indicate that the coverage probability of the illustrative converged cell-less communication networks is higher than the coverage probability of conventional cellular networks when the SINR threshold of user terminal is configured as $-15 \text{ dB} \sim 5 \text{ dB}$. The reason is that the cooperative group formed by local BSs can significantly reduce the interference among BSs by converting the interference within the group into the useful signal.

C. Energy Efficiency in Converged Cell-less Communication Networks

A large number of BSs/APs are ultra-densely deployed in smart cities. Hence, there exists the redundancy for BSs/APs when the traffic load is low in some scenarios, such as the work office in middle nights. The converged cell-less communication network provides a flexible BS/AP sleeping scheme to decrease the energy consumption in smart cities which is controlled by the SDN cloud computing. The detailed BS/AP sleeping scheme is explained as follows.

- 1) A BS/AP can be configured in several states including transferring, ready, listening and sleeping. When a BS/AP is in the transferring state, the BS/AP can transmit data to the specified user terminal or probably quit the active cooperative group due to the dynamic grouping scheme. After that, the BS/AP turns to ready state.
- 2) When a large amount of data are transferred, the transmission power can be dynamic allocated among the members of a cooperative group, according to the channel status between the user and the BSs/APs. A deliberate power allocation scheme will make sense to save energy.
- 3) In low traffic load scenarios, e.g., the work office in midnight, some of BSs/APs can turn to the sleeping state from ready or listening state to save as much energy as possible. To guarantee the coverage probability of converged cell-less communication networks, the active BSs/APs adaptively increase the coverage area by increasing the transmission power or grouping more cooperative members if necessary.

Utilizing the same illustrative simulation scenario in the Fig. 4, 20 active BSs are selected in random transferring or ready state and the other BSs are configured into the sleeping state in converged cell-less communication networks. When a BS is sleeping, its neighbor BSs is configured to serve active users to guarantee coverage probability in this area. Considering

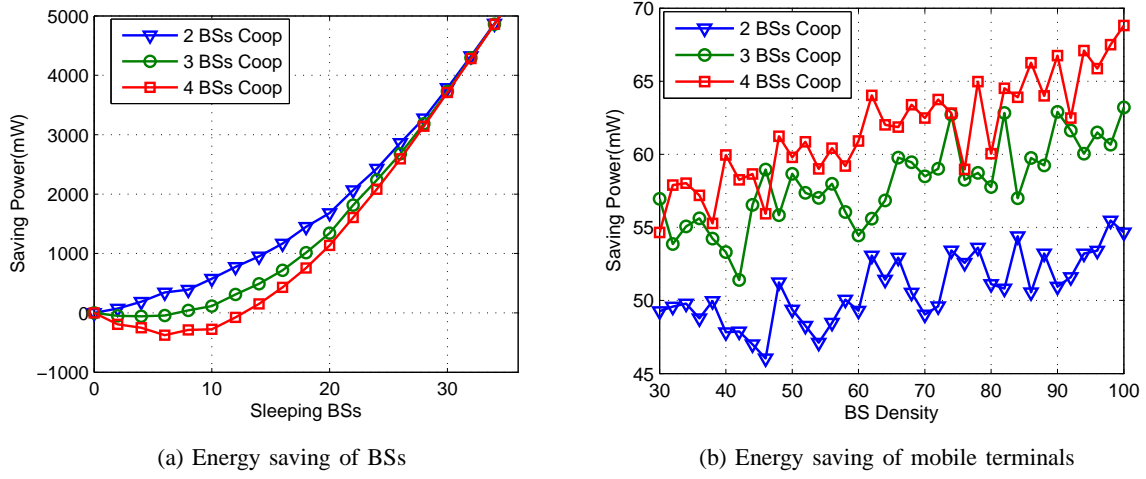


Fig. 5. Energy saving in cell-less networks

small BSs in 5G mobile communication systems, the consumption power of BSs is configured as 10, 50, 80, 200 mW corresponding to the sleeping, listening, ready and transferring states, respectively. The energy saving of converged cell-less communication networks with respect to the number of sleeping BSs considering different number of cooperative BSs is illustrated in Fig. 5(a). Numerical results indicate that the energy saving of BSs increase with the increase of the number of sleeping BSs in the illustrative converged cell-less communication networks. Moreover, the cooperative group of two BSs achieves the maximum energy saving of BSs compared with the cooperative group of three and four BSs in converged cell-less communication networks.

Without loss of generality, the original transmission power of mobile terminal is configured as 100 mW and then the received data rate in non-joint reception scenario can be obtained by simulation firstly. When the joint reception scheme is adopted in converged cell-less communication networks, the mobile terminal can adaptively adjust the transmission power to acquire the same data rate as non-joint reception scenario. When the joint reception is configured at uplinks, the energy saving of mobile terminal is shown in Fig. 5(b). Numerical results show that the energy saving of mobile terminal increases with the increase of the number of cooperative BSs in the illustrative converged cell-less communication networks. These results imply that the converged cell-less communication networks save energy not only at BSs but also at the mobile terminals.

IV. FUTURE CHALLENGES FOR CONVERGED CELL-LESS COMMUNICATIONS IN SMART CITIES

A. Cooperation in Ultra-Densified Wireless Transmitters

In the future smart cities, there exist not only a larger number of BSs but also many other WLAN APs and IoT nodes. In this case, these wireless transmitters are ultra-densely deployed in smart cities. All these wireless transmitters could be converged to provide information to users by a cell-less network architecture. The cooperative communication in ultra-densified wireless transmitters is an attractive solution for converged cell-less communication networks. However, the association relationship of the cooperative group can not be fixed in advance considering heterogeneous wireless transmitters in different wireless networks. In this article, we discuss the potential grouped solutions and validate the advantages in the mobile user coverage probability and the energy saving in smart cities. Anyway, there still exist many challenges need to be investigated. For instance, how to trade-off the complex and efficiency metrics in cooperative schemes of converged cell-less communication networks. When the large data rate is available for mobile terminals, how to realize the backhaul traffic in converged cell-less communication networks is a great challenge especially considering different transmission capacities of heterogeneous wireless networks [14]. The cooperative backhaul solution is a potential solution to satisfy requirements of the big data collection and the environment awareness from smart cities. As a consequence, the investigation of cooperative backhaul schemes in converged cell-less communication networks is an emerging issue for future smart cities.

B. Data and Control Information in Smart Cities

To support the cooperative transmission in converged cell-less communication networks, a part of control information need to be separated from the transmission data and then the common data could be easily transmitted and converged in smart cities. Considering the difference among heterogeneous wireless networks and the architecture of converged cell-less communication networks, it is an important challenge to design the compatible protocol of converged cell-less communication networks. Moreover, the information and data in smart cities have different priority and security level. In this case, the control information of transmission data can not be separated in some specified scenarios of smart cities, for some reasons such as the personal

privacy and the public security. Therefore, a special scheme maybe need to be included into 5G converged cell-less communications for smart cities. In technology level, it is also a troubled problem to execute a single special scheme in all heterogeneous devices even these devices belong to different owners.

C. Cloud and Cache Computing in Converged Cell-less Communications

As discussed in this paper, the cell-less communications provide a flexible solution in coverage and energy efficiency for future smart cities. The cell-less communications can solve the heterogeneous issues in physical level. To match the advantages brought by the cell-less communications, the cloud and cache computing schemes are expected to collaborate with cell-less communications in smart cities. How to coverage the cloud, cache and cell-less communication into the uniform architecture for supporting smart cities is a true challenge for researchers around the world. One of possible way is explored to coverage above three architectures by the converged data information. However, there exist different definitions and understandings for the data and information in cloud, cache and cell-less communications in smart cities. More studies need to be carried out to investigate the converged cloud, cache and cell-less communications. Consquently, the smart cities will be a good platform to draw the dream of converged cloud, cache and cell-less communications [15].

V. CONCLUSION

The information and data generated from different types of heterogeneous wireless networks are converged to provide the ubiquitous service in smart cities. To support mobile users in smart cities, the idea of converged cell-less communication networks is proposed to break the conventional celled architecture of cellular networks and support the flexible mobile user association scheme considering the application requirements and wireless channel status. With the deployment of 5G ultra-dense wireless networks in smart cities, the cooperative group communication is designed for the 5G converged cell-less communication networks. Simulation results indicate that the coverage probability and the energy saving at BSs and mobile terminals are improved in 5G converged cell-less communication networks. Based on the analysis and illustrative results, it can be concluded that the converged cell-less communication scheme is a promising way to match the high demand for coverage and rate in future smart cities, because of

its flexibility and unitarity. Considering there should be many complicated factors in the future smart cities, such as the high demand caused by crowded people, the serious obstacle due to a lot of buildings and the heavy interference in dense streets, the converged cell-less communication networks can play a critical role because it can converge different communication technologies and provide seamless transmission and thus improve coverage and energy efficiency by reducing unnecessary interference. With the development of smart cities, 5G networks still need to be further investigated for solving new challenges in smart cities.

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